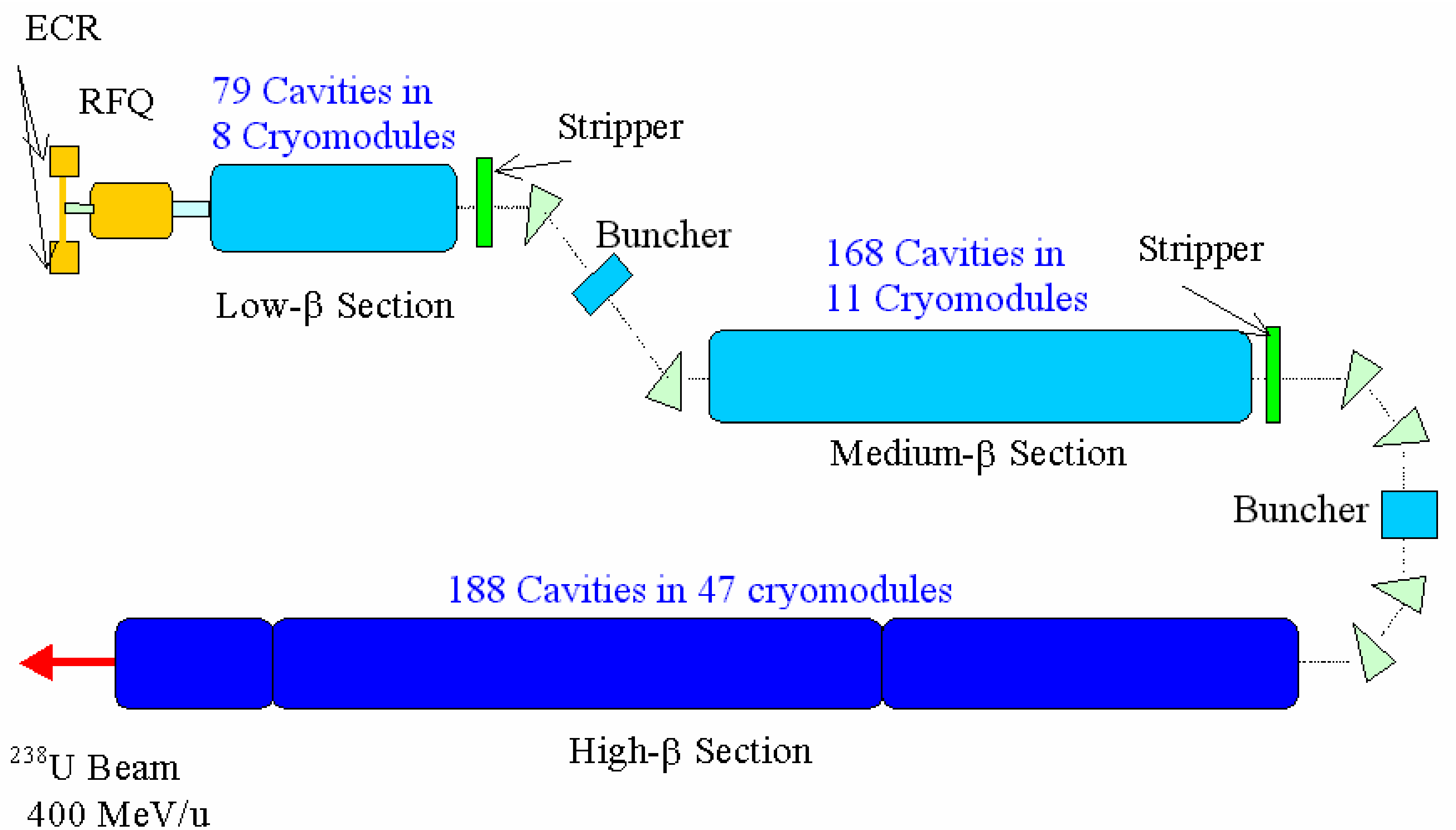
Elements of the RIA Driver Linac



RIA Driver Linac – Superconducting Resonator Configuration

(configured for uranium 28-29+ input at beta = .01749, stripping at frequency transitions)

Beta	Type	Freq (MHz)	Length (cm)	Eacc (MV/m)	Voltage (MV)	Phase deg.	No. Cavities / Section Injector	Middle	Final
0.021	3 DT	57.5	18	4	0.62	-30	2		
0.030	3 DT	57.5	26	4	0.90	-30	5		
0.062	1 DT	57.5	20	5	0.87	-30	32		
0.128	2 DT	115.0	36	4	1.25	-30	40		
0.190	2 DT	172.5	36	5	1.56	-30		72	
0.380	2 DT	345.0	36	5	1.56	-30		96	
0.490	6 Cell	805.0	55	8.28	3.93	-25			76
0.610	6 Cell	805.0	68	10.22	6.04	-25			84
0.810	6 Cell	805.0	91	12.56	9.85	-25			28

Total Cavities = 435		Section Cavities =	79	168	188
Total Voltage = 1421	(MV)	Section Voltage =	77.6	261.9	1081.4

Costing Methodology and Assumptions

Assumptions:

- Production of SC cavities coordinated by ANL using commercial vendors for machining, forming, and EB welding of components
- SC Cavities processed and tested at ANL
- Final assembly of cryomodules performed at ANL

Methods:

- Experience at ANL with the SC ion linac ATLAS
- Vendor quotes

Some Primary Contributors:

•Engineering analysis & support	Advanced Energy Systems, Inc
•Cryostat engineering & fabrication	Meyer Tool & Mfg. Co.
•Electron beam welding	Sciaky, Inc.

Some Contributors to Pricing Backup

• Cryogenic Components	Meyer Tool & Mfg
• Niobium & Vanadium	Wah Chang
• Niobium Seamless Tubing	Metal Technology, Inc.
• Stainless Steel Type 304	Sterling Aircraft Materials Ltd.
• Explosion Bonded Nb-SST	Northwest Technical Industries
• Hydroforming	Aero-trades Manufacturing
• Die Stamping of Stiffeners	Short Run Stamping Co., Inc.
• Bellows/Flange Assemblies	Metal Flex Welded Bellows, Inc.
• Couplers & Magnets	Lawrence Livermore Nat'l. Lab.

RIA Driver Drift-tube Linac Section – Cost Breakout

1.1 Research & Development	**($8,782)**		**(not included in total)**
1.1.1 System Studies		($282)	
1.1.2 Component Prototyping		($8,500)	
1.2 System Design	**$6,626**		
1.2.1 Conceptual Design		($1,146)	
1.2.2 Preliminary Design		$2,640	
1.2.3 Final Design		$3,985	
1.3 Driver Accelerator Systems	**$35,296**		
1.3.2 Drift Tube Linac Section		$32,696	
1.3.4 Beam Stripper & Charge State Selection Systems (2 units)		$2,500	
1.3.5 Beamline Secondary Systems - Metrology		$100	
1.6 RF Systems	**$14,134**		
1.6.1 Signal Source Systems		$81	
1.6.2 Drift Tube Accelerator Systems		$14,053	
1.7 Cryogenic Supply & Distribution Systems	**$8,310**		
1.7.1 Liquid Helium Refrigerator Systems		$5,310	
1.7.2 Distribution System		$3,000	
1.10 System Controls and Diagnostic Systems	**$3,356**		
1.10.1 System Controls		$1,972	
1.10.2 Diagnostics Systems		$1,384	
1.11 Environmental, Safety, Health, and Radiation Control Syst	**$655**		
1.11.2 Access Control & Interlock Systems		$655	
1.13 Project Management & Control	**$4,058**		
1.13.1 Program Office		$780	
1.13.2 Project Sciences		$609	
1.13.3 Project Engineering		$1,280	
1.13.4 System Engineering		$785	
1.13.5 Program Support		$302	
1.13.6 Business Operations		$302	
TOTAL	**$72,435**		

NOTE: Costs are given in k$

RIA Driver Drift-tube Linac Section – Cost Breakout

1.1 Research & Development	($8,782)		
1.1.1 System Studies		($282)	(not included in total)
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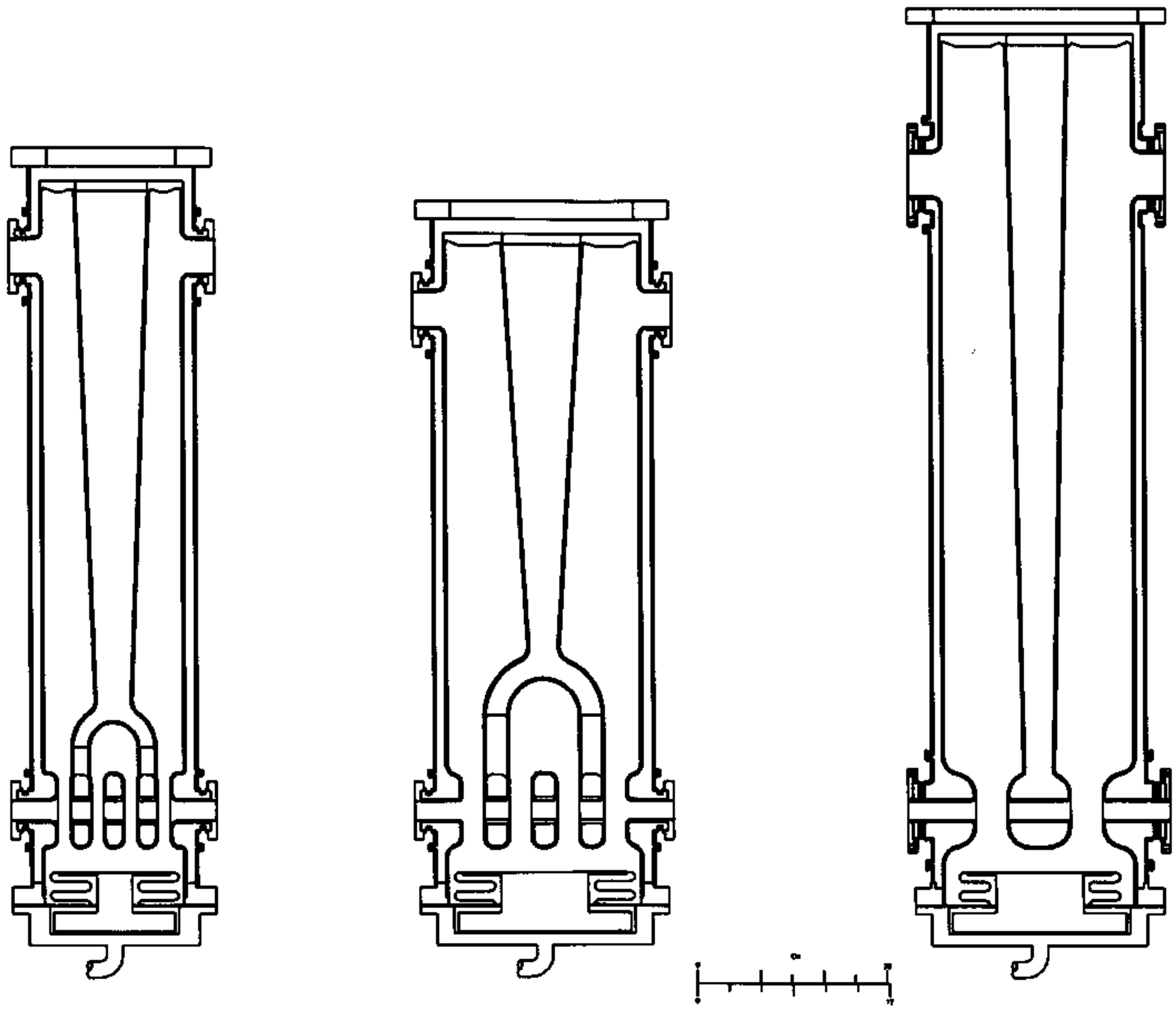
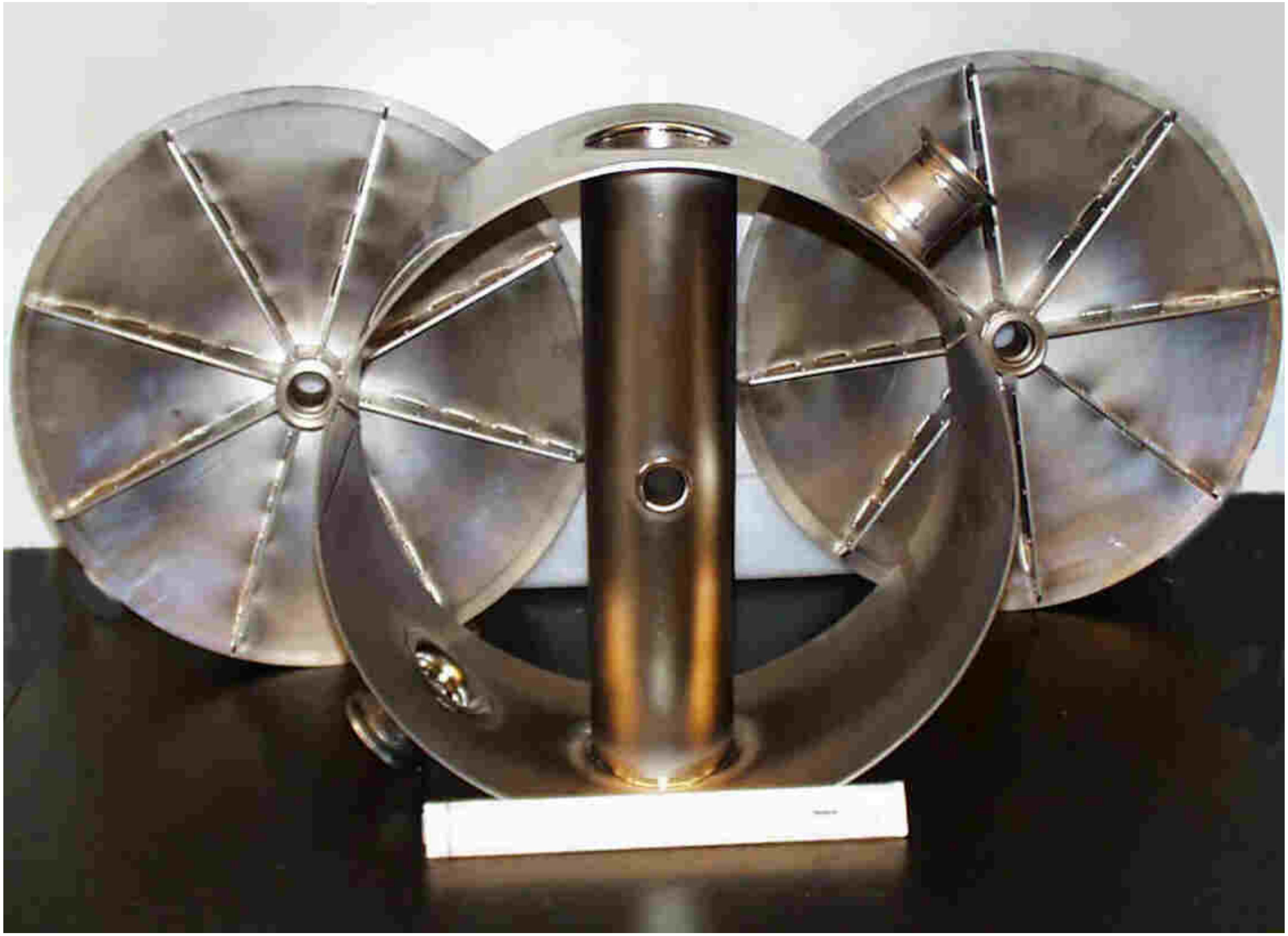
TOTAL	$72,935		

NOTE: Costs are given in k$

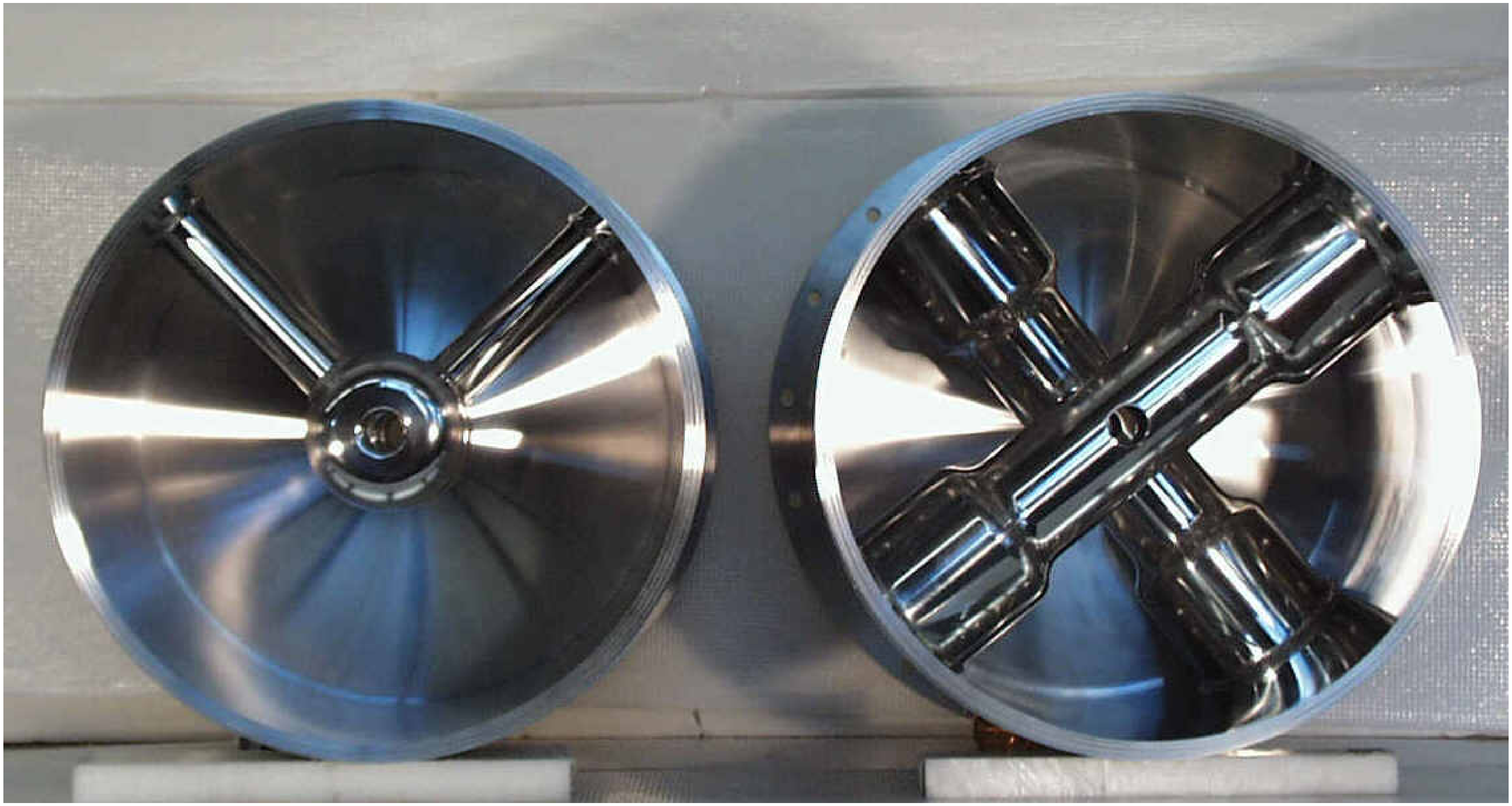
57.5 MHz, QWR-class cavities for the RIA Driver LINAC



Elements of the prototype niobium 350 MHz spoke cavity prior to final (closure) EB welding



Warm model of the two-cell 175 MHz lollipop cavity on left, of the two-cell 350 MHz spoke cavity on right



Some Costing Assumptions:

Variable	Value	Comments
Number of 0.03 Beta Fork Resonator Cavities	2	
Number of 0.03 Beta Fork Resonator Cavities	5	
Number of Quarter Wave Resonator Cavities	32	
Number of 175 MHz Cavities	112	(72 Lollipop + 40 Split-ring)
Number of 345 MHz Cavities	96	
RRR 100 Niobium Drawn Tubing (1.18 ID x .125	$1,990.00	per 12"-13" segment
RRR 100 Niobium Drawn Tubing (2.18 ID x .125	$3,390.00	per 12"-13" segment
0.125 in RRR 100 Niobium Sheet	$183.00	per lb.
0.75 in RRR 100 Niobium Plate	$147.00	per lb.
0.125 in 304L SS Sheet	$3.50	per lb.
Vanadium Cost per pound	$441.00	per lb.
Density of 304L Stainless Steel	489.02	Lbs./ft3 (0.283 lbs./cu in)
Density of Niobium	533.89	Lbs./ft3 (8.57 gm/cc)
Density of Vanadium	381.89	Lbs./ft3 (0.221 lbs./cu in)
Machining learning curve percentage	95%	

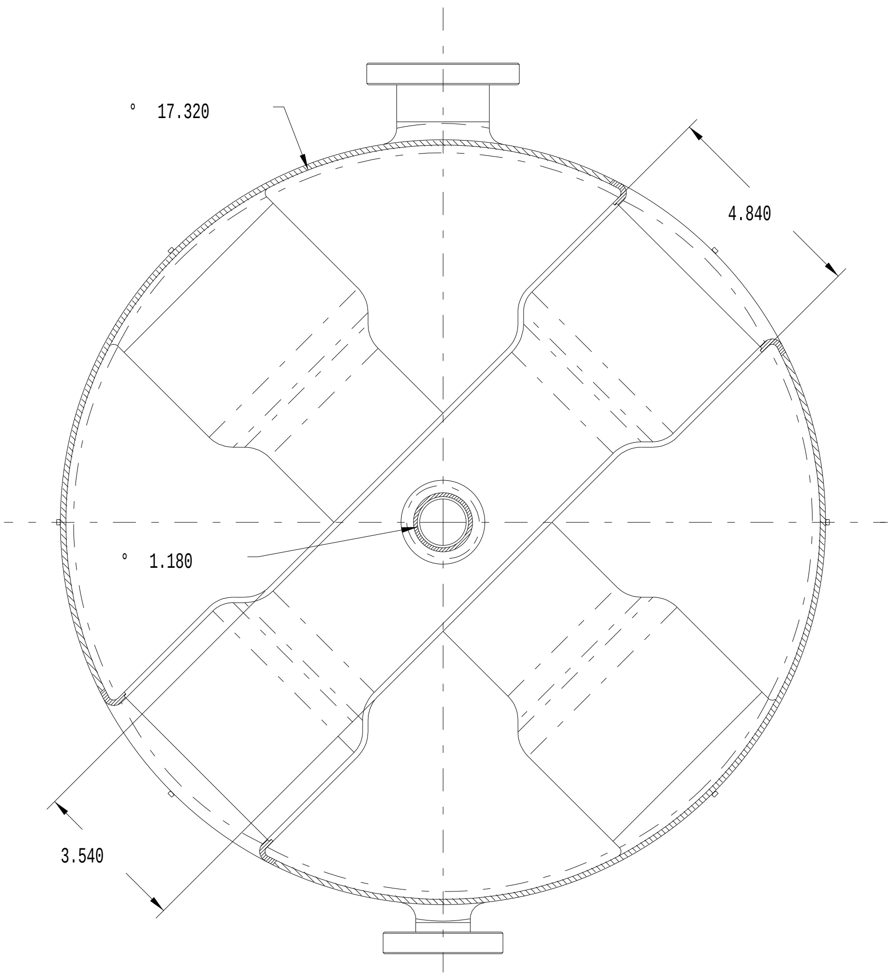
Breakdown – Cavity Fabrication Costs

Cavity Type	Quantity	Raw Material		Services		Machining		Tooling		Total Cost
0.021 FORK	2	$87,553	36%	$32,988	14%	$21,638	9%	$98,400	41%	$240,579
0.03 FORK	5	$262,548	56%	$82,470	18%	$43,513	9%	$76,200	16%	$464,731
QWR Cavity	32	$1,454,954	64%	$540,928	24%	$203,118	9%	$60,800	3%	$2,259,800
175 MHZ Cavity	112	$3,374,287	58%	$2,043,733	35%	$312,709	5%	$71,705	1%	$5,802,435
345 MHZ Cavity	96	$3,208,393	62%	$1,315,692	26%	$595,969	12%	$16,600	0%	$5,136,654

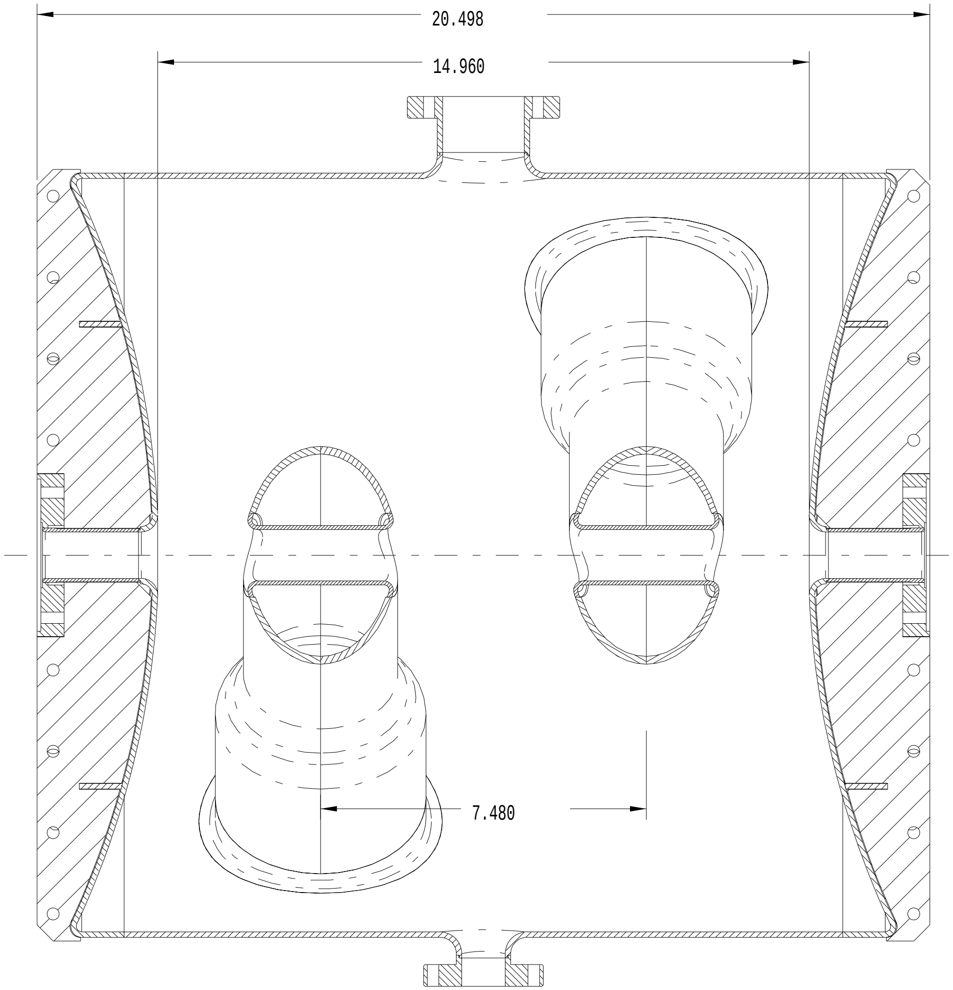
Average costs for the finished cavities are:

Cavity Type	Quantity	Avg Cost/Cavity
0.021 FORK	2	$ 120,289
0.03 FORK	5	$ 92,946
QWR Cavity	32	$ 70,619
175 MHZ Cavity	112	$ 51,807
345 MHZ Cavity	96	$ 53,507

Section Views – 350 MHz Spoke Cavity

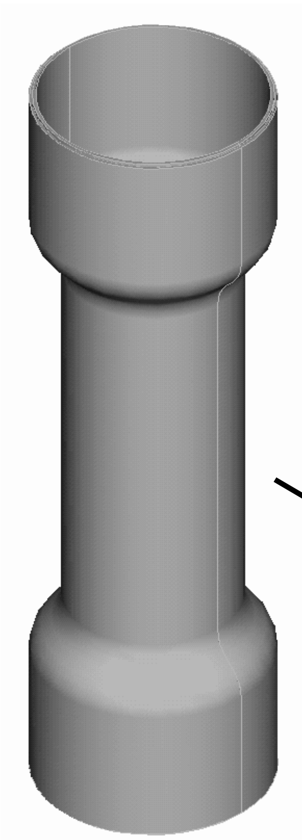


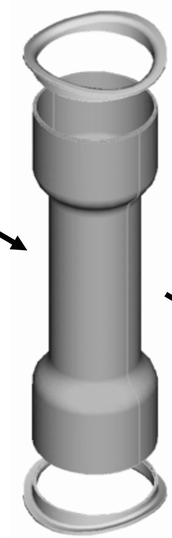
SECTION B-B



SECTION A-A

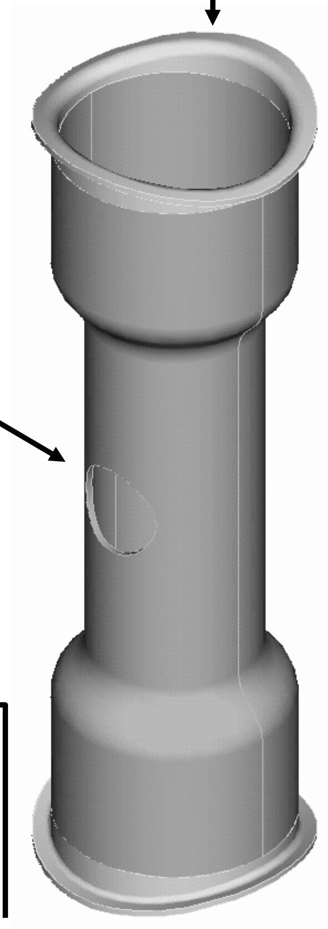
Spoke Fabrication - Assembly

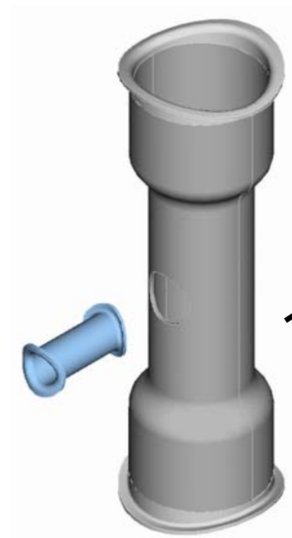


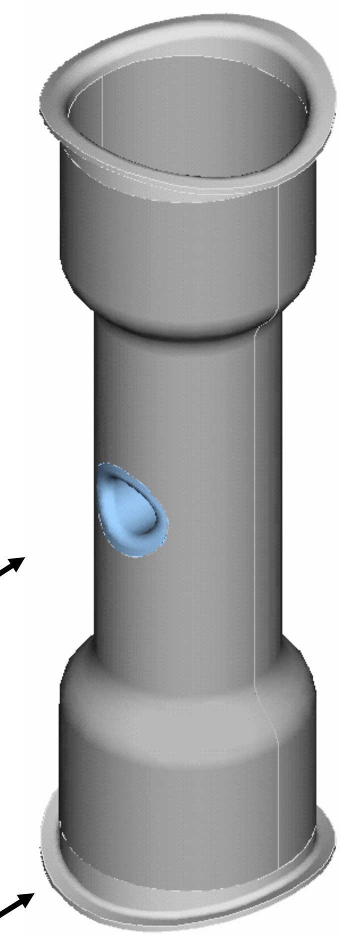


Spoke Sub-Assembly One: 2 Sub-Assy's Required

1. Perform a light BCP on Spoke Saddles and Spoke Tube sub-assemblies.
2. Assemble Spoke Saddles and Spoke Tube sub-assembly into EB Weld tooling..
3. EB Weld Spoke Saddles to Spoke Tube sub-assembly.
4. Bore beam tube saddle holes through spoke tube.







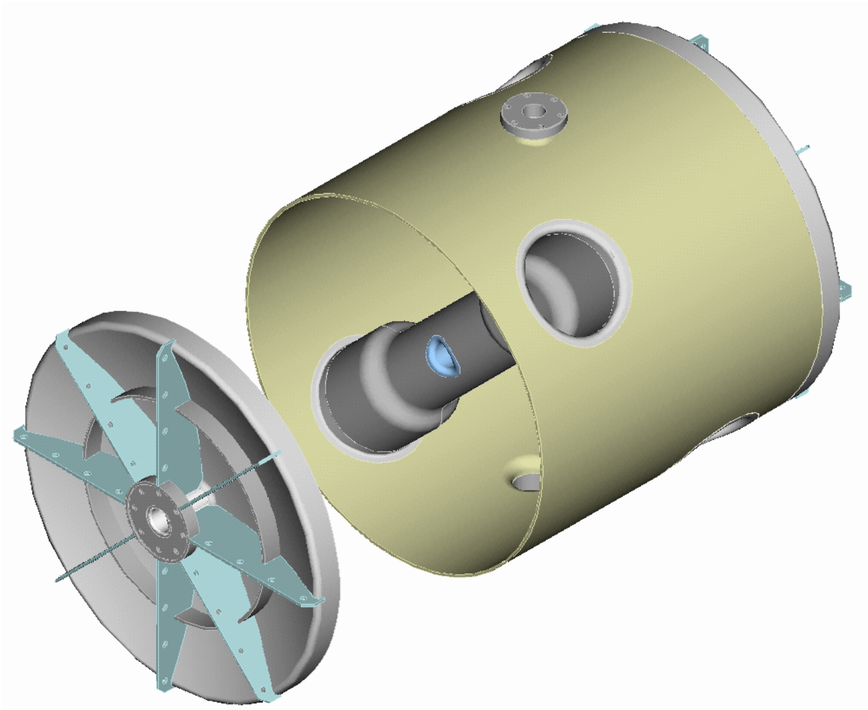
Spoke Tube Sub-Assembly: 2 Sub-Assy's Req'd

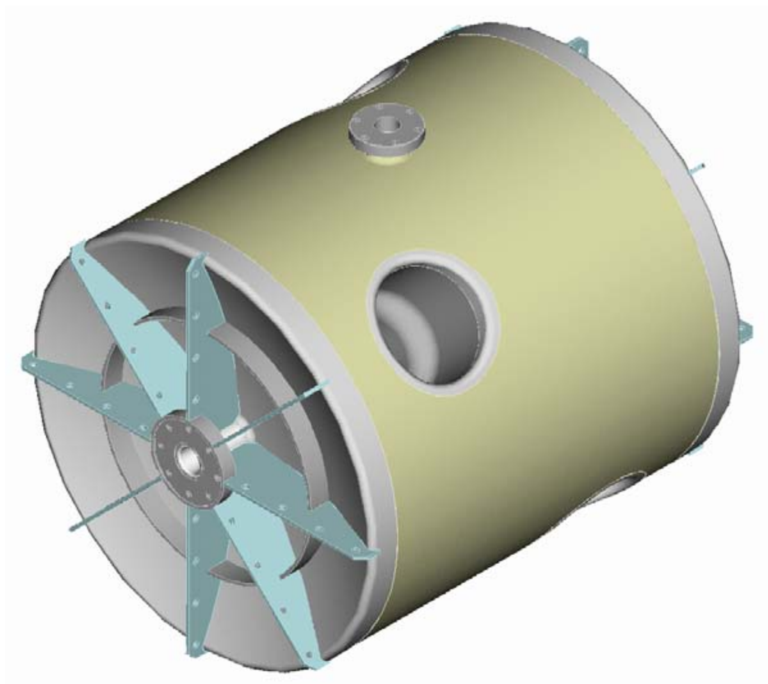
1. Perform a light BCP on Spoke Halves.
2. Assemble Spoke Halves into EB Weld tooling.
3. EB Weld (2) spoke halves-together creating (1) spoke tube.

Spoke Sub-Assembly: 2 Sub-Assy's Req'd

1. Perform light BCP on Spoke Beam Tubes and Spoke Tube sub-assemblies.
2. Assemble Spoke Beam Tube and Spoke Tube sub-assembly One into EB Weld tooling..
3. EB Weld Spoke Beam Tube into Spoke Tube sub-assembly.
4. Machine saddle dia. on both ends of spoke true to spoke bore centerline.

End Wall Installation

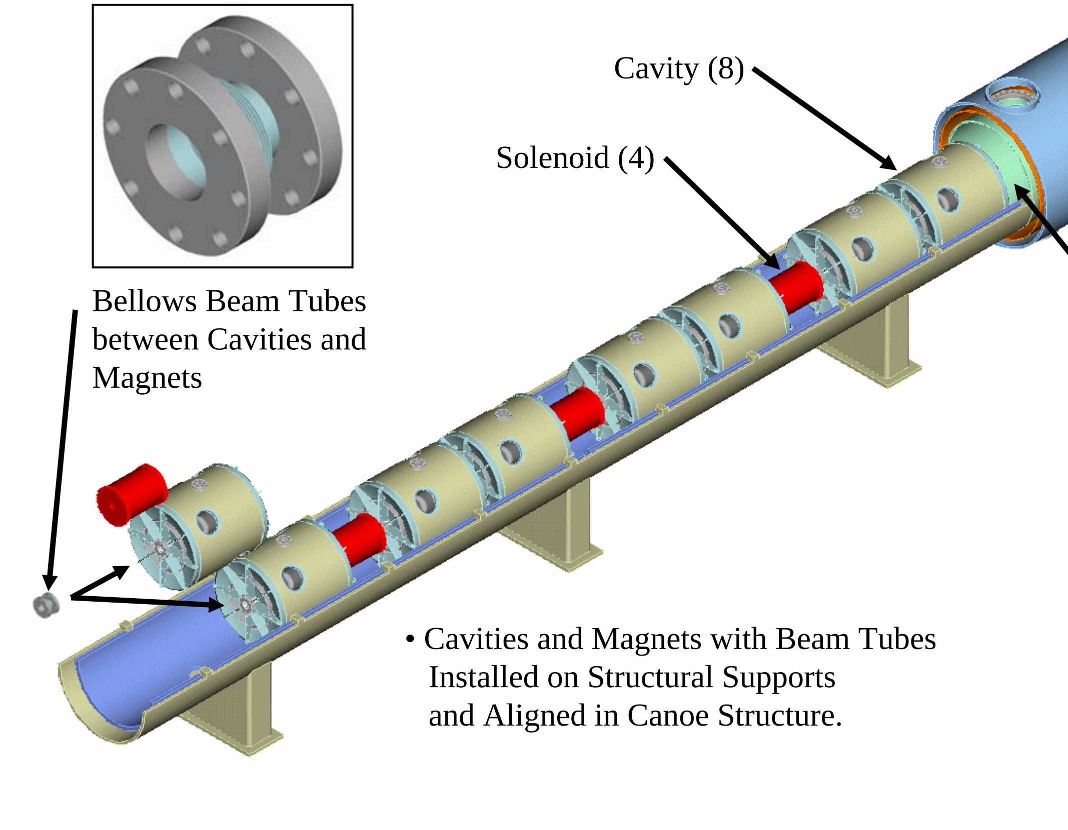


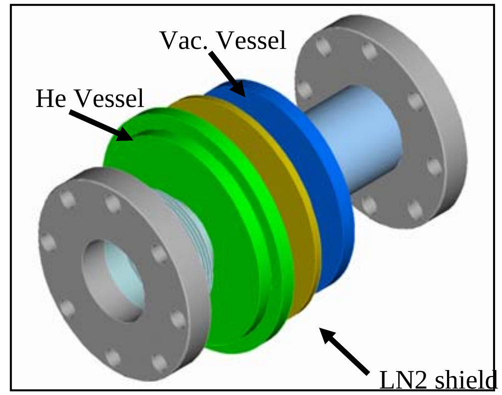


Double Spoke Cavity Assembly:

1. Perform a light BCP on the Tank Sub-Assembly and (2) End Wall Sub-Assemblies.
2. Assemble (1) Tank Sub-Assembly and (2) End Wall Sub-Assemblies into the EB Weld tooling that will align and position the End Walls Sub-Assemblies in respect to the tank's beam tube centerline.
3. EB Weld the (2) End Wall Sub-Assemblies to the Tank Sub-Assembly creating .a Double Spoke Cavity Assembly.

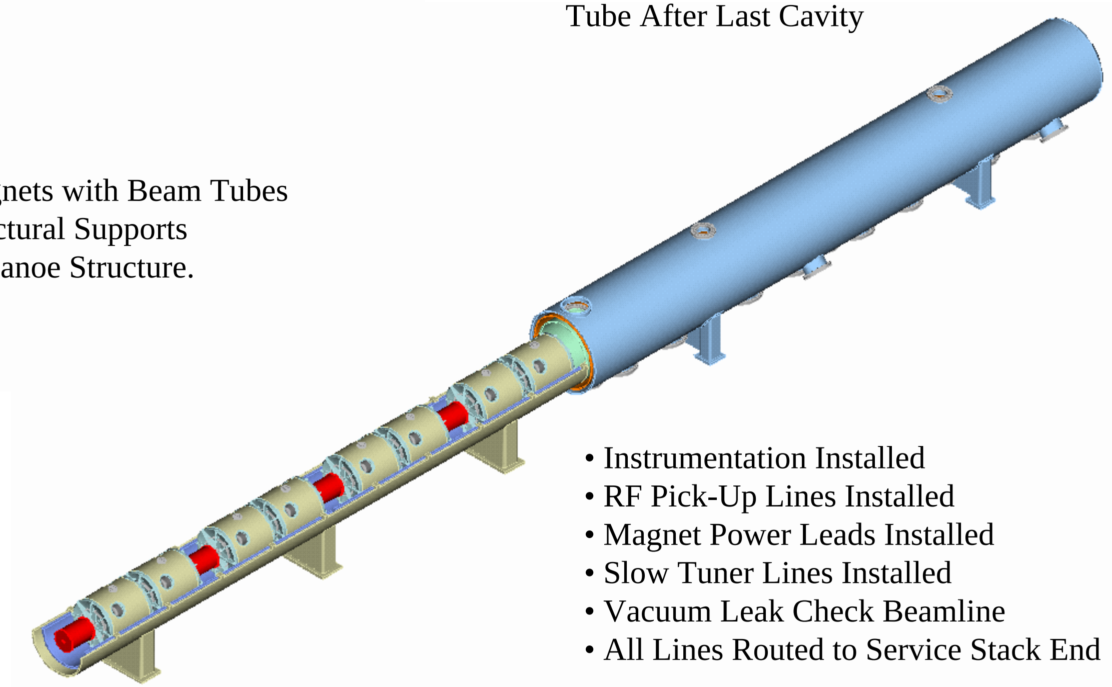
Double Spoke Cavity & Solenoid Installation





End Bellows Beam Tube After Last Cavity

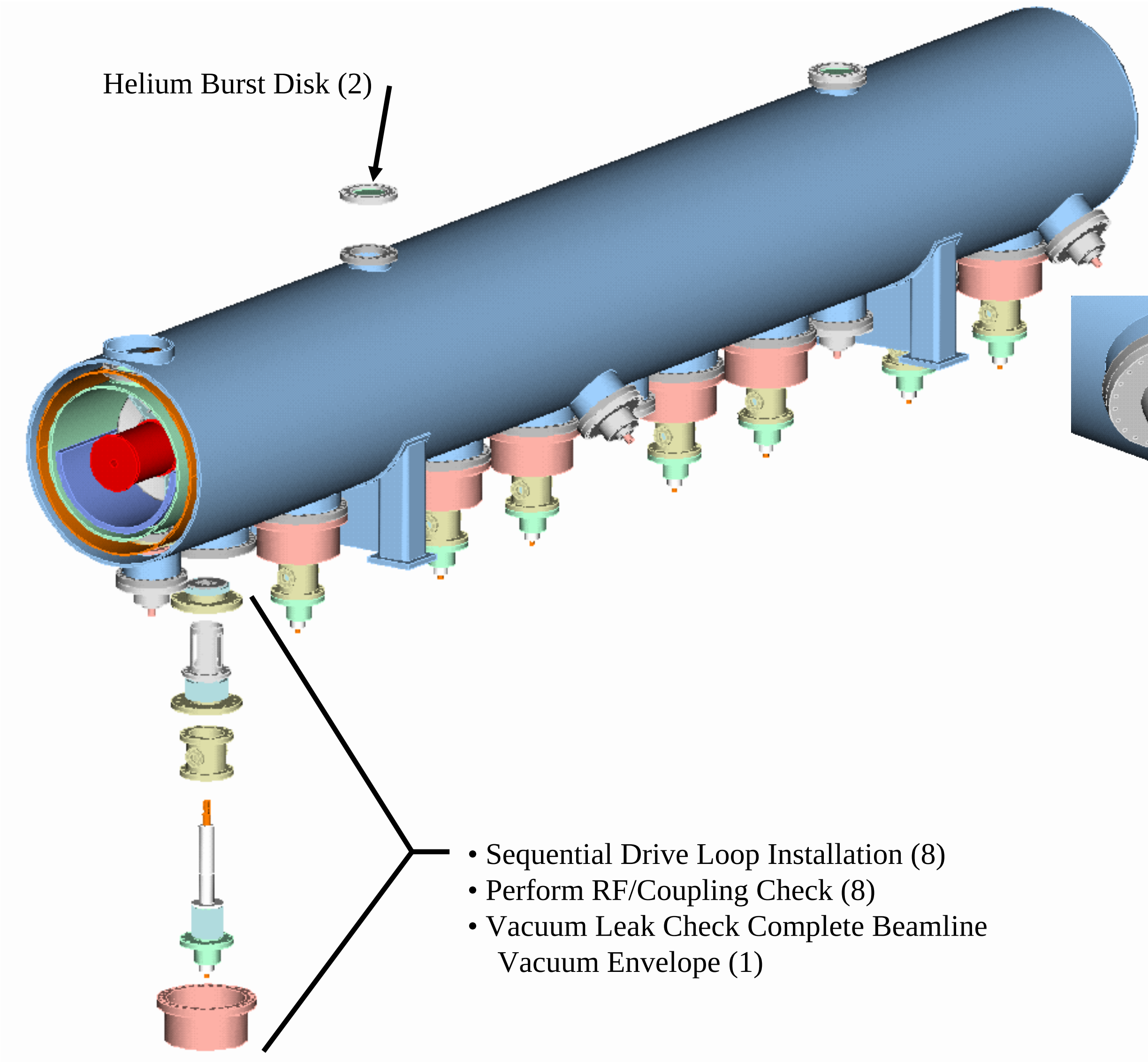
- Cavities and Magnets with Beam Tubes Installed on Structural Supports and Aligned in Canoe Structure.



Assembly Station C2

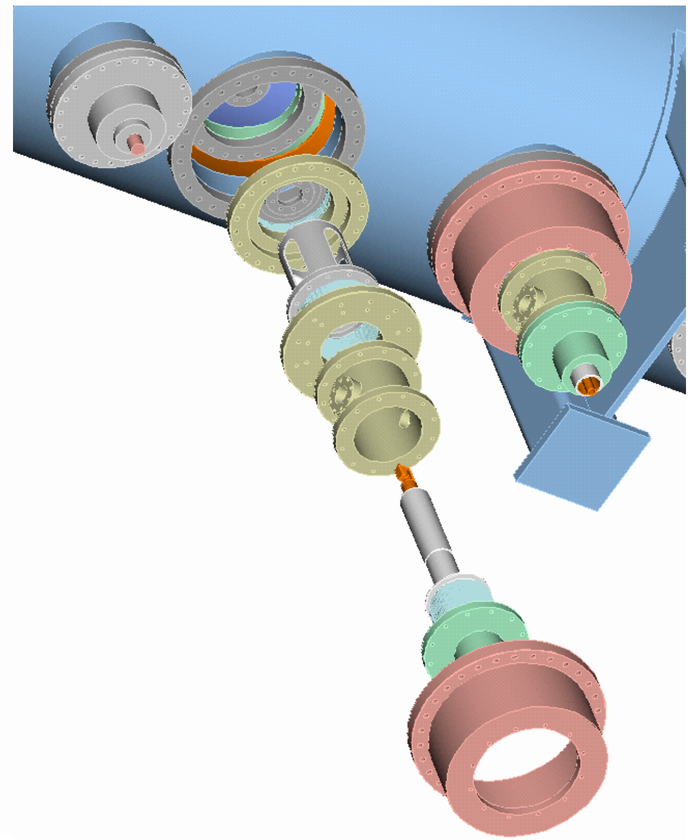
- Instrumentation Installed
- RF Pick-Up Lines Installed
- Magnet Power Leads Installed
- Slow Tuner Lines Installed
- Vacuum Leak Check Beamline
- All Lines Routed to Service Stack End

Drive Coupler Installation (8 Places)

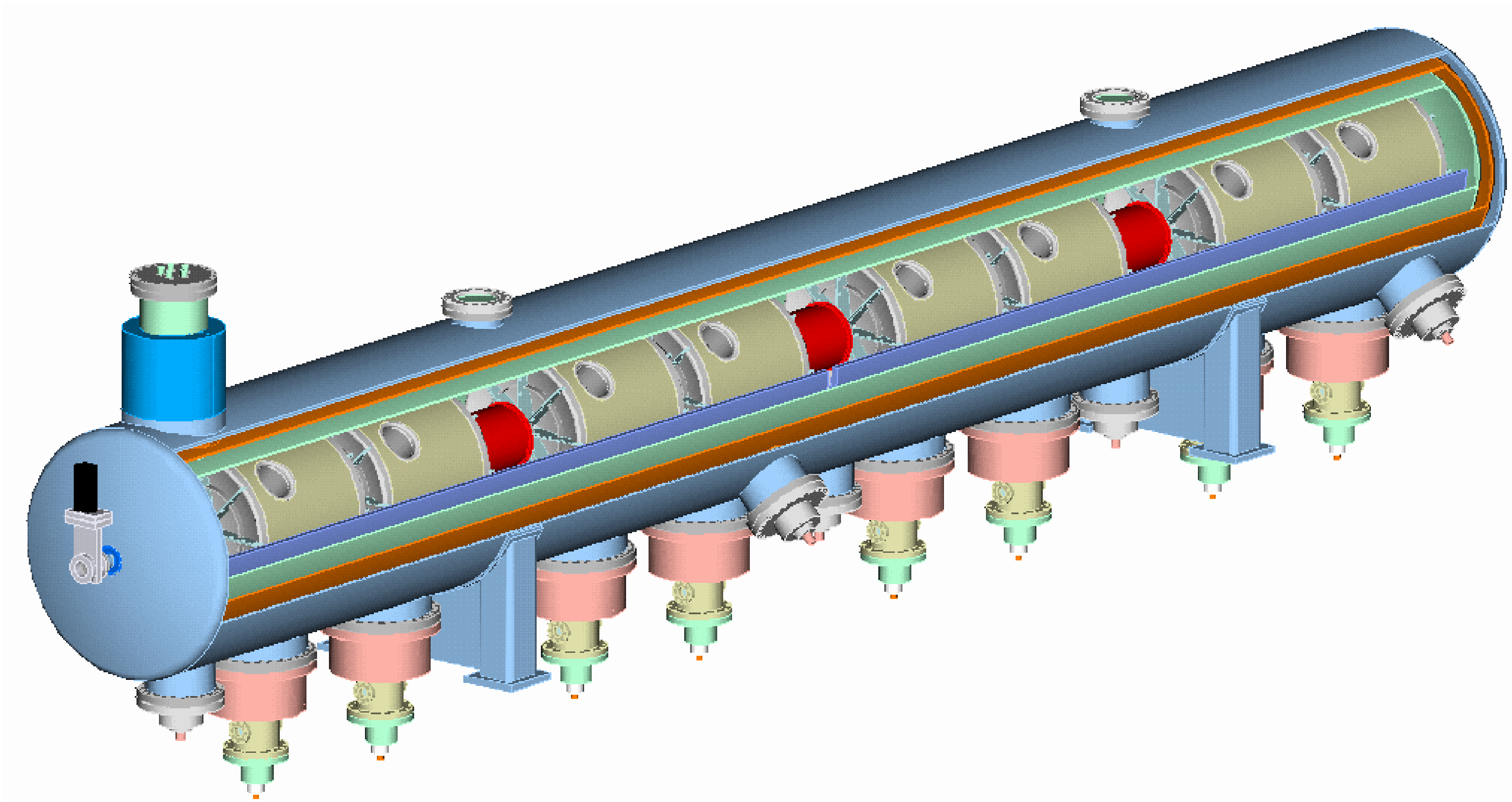


- Sequential Drive Loop Installation (8)
- Perform RF/Coupling Check (8)
- Vacuum Leak Check Complete Beamline Vacuum Envelope (1)

Assembly Station C3

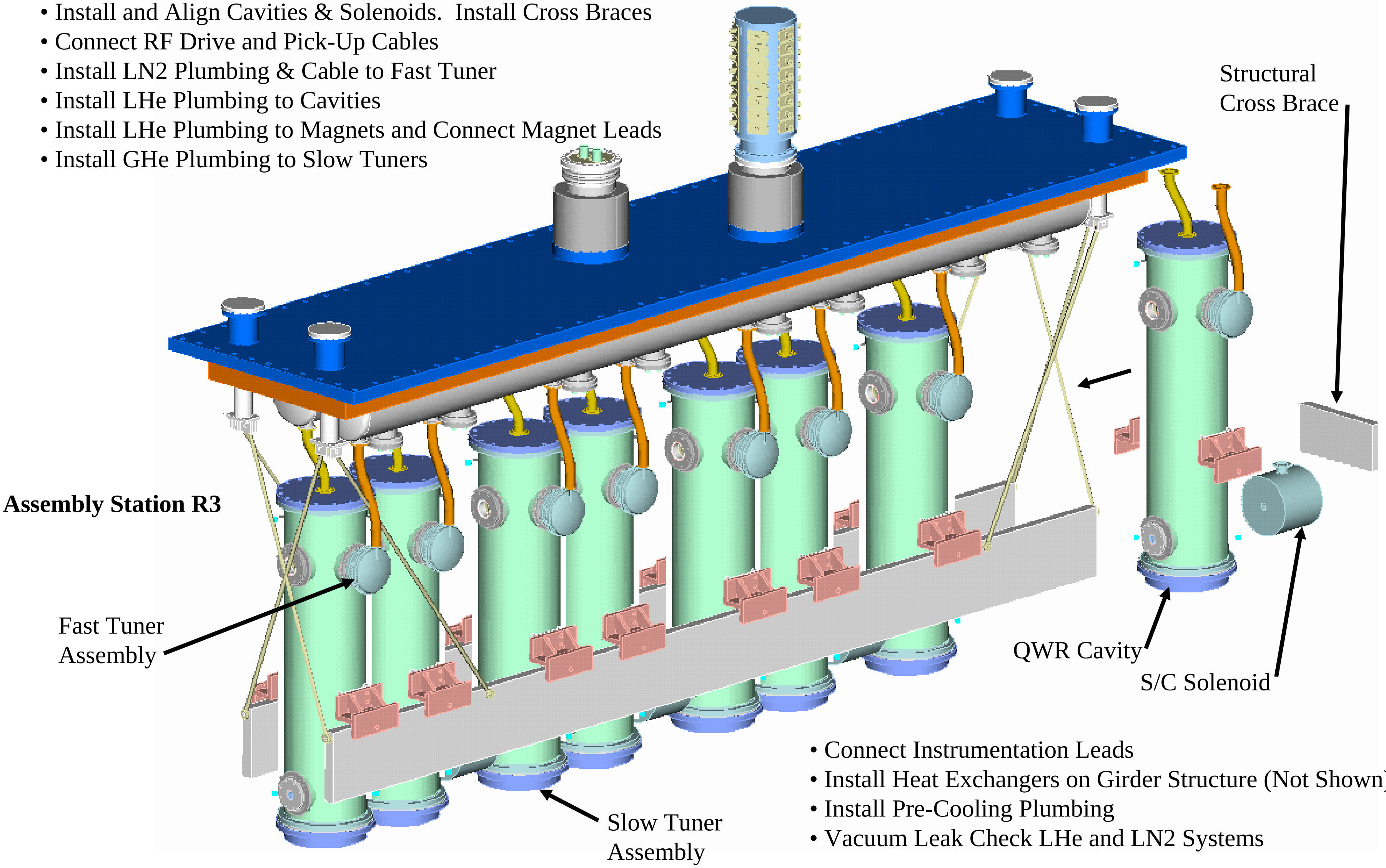


Round Cryomodule - Cut-away View



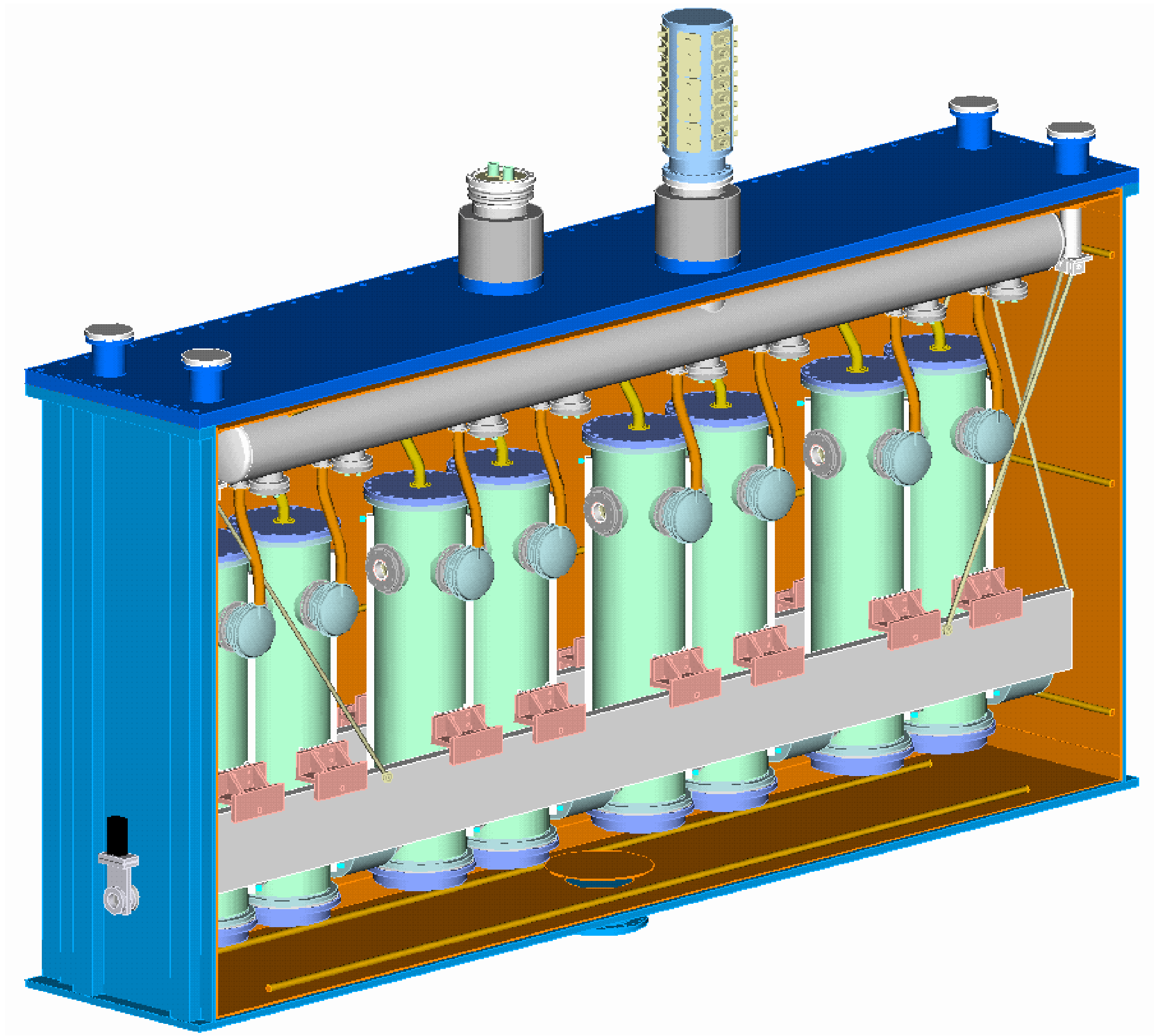
Box Cryomodule - Cavity & Solenoid Installation

- Install and Align Cavities & Solenoids. Install Cross Braces
- Connect RF Drive and Pick-Up Cables
- Install LN2 Plumbing & Cable to Fast Tuner
- Install LHe Plumbing to Cavities
- Install LHe Plumbing to Magnets and Connect Magnet Leads
- Install GHe Plumbing to Slow Tuners

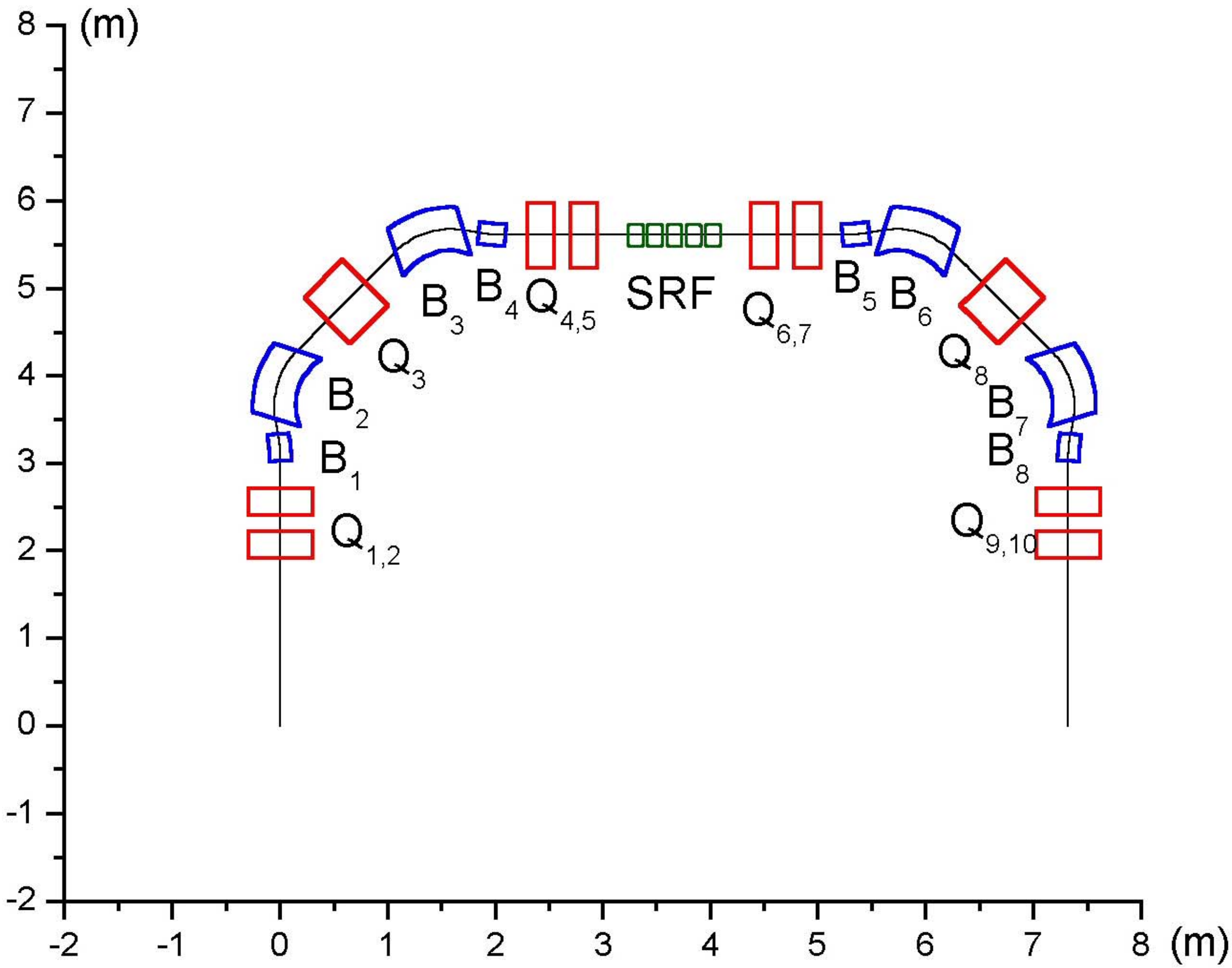


- Connect Instrumentation Leads
- Install Heat Exchangers on Girder Structure (Not Shown)
- Install Pre-Cooling Plumbing
- Vacuum Leak Check LHe and LN2 Systems

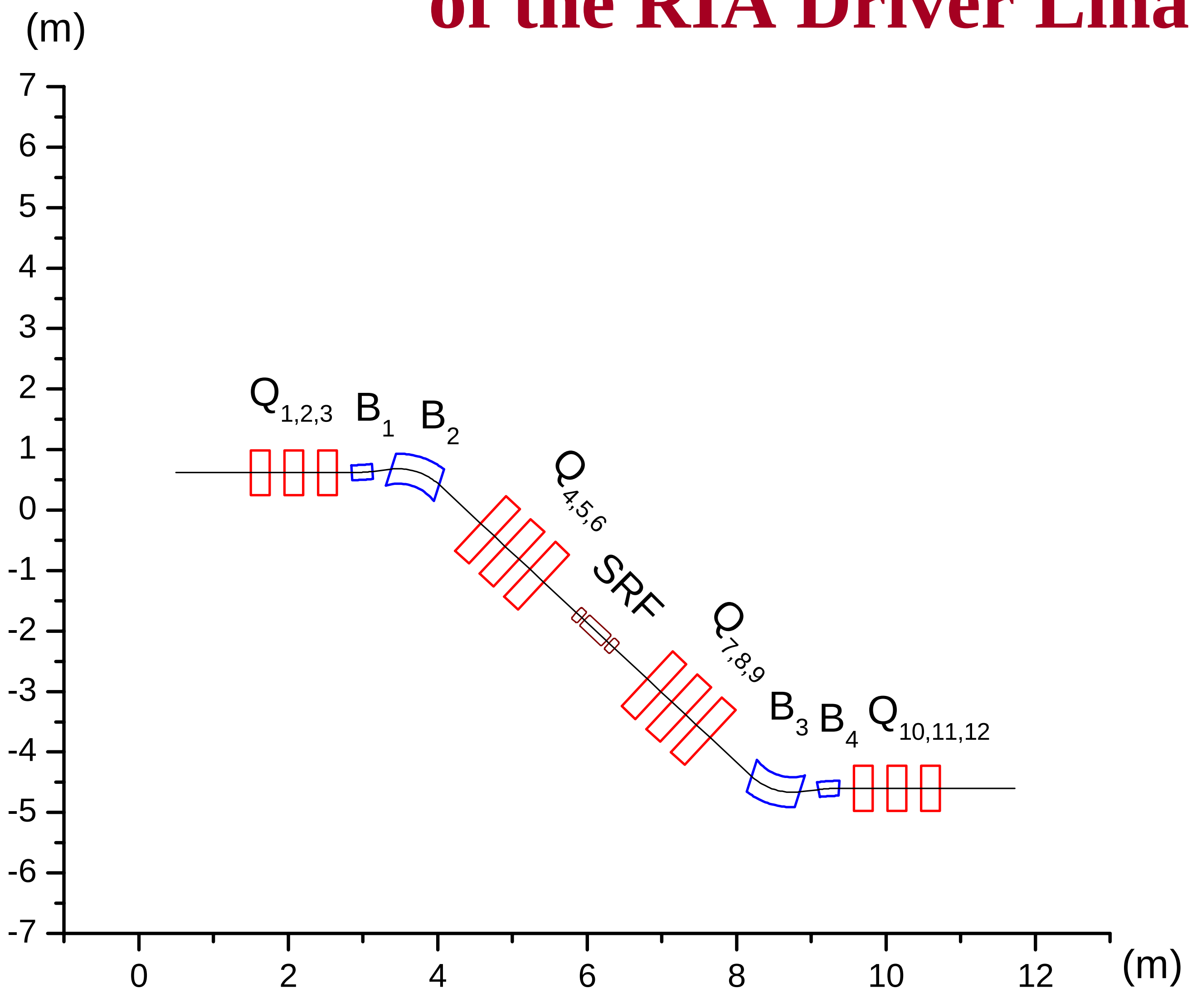
Box Cryomodule – Cut-away View



Elements of the 180 degree bend region of the RIA Driver Linac



Elements of the Dogleg Bend Region of the RIA Driver Linac



Cost Breakout for Spoke-cavity Linac Section

			CM unit costs
1.3 Driver Accelerator Systems			
1.3.2 Drift Tube Linac Section			
1.3.2.2 Post-stripper Drift-tube Section			
1.3.2.2.3 Cryomodule #20-31 (0.38 β Cavities)	**$12,671**		
1.3.2.2.3.1 Cavities		**$6,625**	**$1,056**
Fully dressed cavity cost of 69 k$ = bare cavity (54 k$) + tuners & power coupler			
1.3.2.2.3.2 Cryostats		**$2,909**	
1.3.2.2.3.3 Internal Cryogenics		**$504**	
1.3.2.2.3.4 Focusing Magnets		**$420**	
1.3.2.2.3.5 Vacuum Systems		**$1,032**	
1.3.2.2.3.6 Cavity Processing & Cryostat Assembly		**$1,182**	
1.3.2.4 Cryomodule Installation & Checkout in Tunnel	**$362**		**$12**
1.6 RF Systems			
1.6.2 Drift Tube Accelerator Systems			
1.6.2.4 Circular Cyomodule RF Power Systems	**$9,364**		**$360**
1.6.2.4.1 High Level RF Power		**$3,150**	
1.6.2.4.2 Low Level RF Power		**$4,676**	
1.6.2.4.3 Miscellaneous Hardware		**$1,538**	
Cost per Cryomodule - w/o contingency			**$1,428**

Costs are given in k$

Stripping & Charge-state Selection

Elements	Dogleg Bend	180 Bend	Cost
Quadrupole magnet			**$210**
Number of magnets	6	8	
Effective length	0.25 m	0.25 m	
Bore radius	30 mm	30 mm	
Pole field	0.5 T	1.0 T	
Quadrupole magnet			**$120**
Number of magnets	6	2	
Effective length	0.25 m	0.4 m	
Bore radius	50 mm	50 mm	
Pole field	0.8 T	0.8 T	
Dipole magnet			**$490**
Number of magnets	2	4	
Effective length	0.3 m	0.3 m	
Bending angle	7 deg	10 deg	
Bore(width $\times$gap)	30 $\times$15 mm$\times$mm	25 $\times$50 mm $\times$mm	
Pole field	0.7 T	2.25 T	
Dipole magnet			**$760**
Number of magnets	2	4	
Effective length	0.7 m	0.8 m	
Bending angle	50 deg	55 deg	
Bore(width $\times$gap)	30 $\times$15 mm$\times$mm	30 $\times$50 mm $\times$mm	
Pole field	2. T	4.5 T	
RF Rebuncher voltage	4.0 MV	1.3 MV	**$920**
Stripper	0.1 mg/cm lithium	8 mg/cm carbon	**$400**
Misc. Systems			**$100**
		TOTAL	**$3,000**